SPECIAL HANDLING

SHC64-9043-671
Copy No. 2

9 November 1964

Dear John:

Transmitted herewith are five (5) copies of the DD-250 form covering the transmittal of the Final Report - A Study of Spatial Filtering Using the Image Enhancement Viewer - under [ ] Task Order No. 4.　STAT

Five (5) copies of the report are also enclosed.

Would you please execute (2) copies of the DD-250 form and return them to [ ] [ ]　STAT

STATOTHR

Very truly yours,

STATOTHR

Contracts Manager

pv
Encls: 10

DECLASS REVIEW by NIMA/DOD

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5. OFFICE ADMINISTERING CONTRACT	6. INSPECTION OFFICE	7. CREDIT VOUCHER OR FILE NO.

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	11. SUPPLEMENTS AND CHANGE ORDERS
	13. ORDER NO. ON SUPPLIER

14. SHIPPED TO—MARK FOR	15. PROC. DIR. OR REQUISITION NO.

STAT

	16. SHIPMENT ORDER NO.

17. SHIPMENT NUMBER ON CONTRACT A. PARTIAL	B. FINAL

(Accountable Office when different)

18. GROSS WEIGHT	19. NET WEIGHT

20. DATE SHIPPED 11/9/64	21. SEAL NUMBERS	22. B/L OR REGISTRATION NO.	23. CAR NO.	24. ROUTING

CONTRACT ITEM NUMBER 25	STOCK AND/OR PART NUMBER AND DESCRIPTION OF ARTICLES (Indicate no. of shipping containers - Type of container - Container no.) 26	UNIT OF MEAS. 27	QUANTITY SHIPPED 28	QUANTITY RECEIVED 29	UNIT COST 30	TOTAL COST 31
	Final Report – A Study of Spatial Filtering Using the Image Enhancement Viewer		5			

Received and Accepted: _____
Authorized Representative

32. APPROPRIATION	C. ARTICLES SHOWN IN COLUMN 29 WERE RECEIVED IN APPARENT GOOD CONDITION, EXCEPT AS NOTED DATE: INCHECKER:
33. INVOICE ROUTING	34. CLASS—CODE	35. ACCOUNT NO.—STORES ACCOUNT	36. DEBIT VOUCHER OR I. O. NO.

A. I CERTIFY THAT THE ITEMS LISTED HEREIN HAVE BEEN INSPECTED BY ME OR UNDER MY SUPERVISION. THEY CONFORM TO CONTRACT, AND HAVE BEEN ACCEPTED, EXCEPT AS NOTED.	B. I CERTIFY THAT I HAVE RECEIVED AND/OR ACCEPTED THE ARTICLES SHOWN HEREIN (For use on Contract No.) EXCEPT AS NOTED.
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10. NAME OF PRIME CONTRACTOR—CITY—STATE	11. SUPPLEMENTS AND CHANGE ORDERS

12. MANUFACTURER OR WAREHOUSE SHIPPED FROM—CITY—STATE	13. ORDER NO. ON SUPPLIER

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FROM:		EXTENSION	NO.
			DATE

TO: (Officer designation, room number, and building)	DATE		OFFICER'S INITIALS	COMMENTS (Number each comment to show from whom to whom. Draw a line across column after each comment.)
	RECEIVED	FORWARDED		
1. Director, NPIC				
2. ATTN: ▨ 25X1A				
3.				
4.				Received 30 November 1964
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6.				25X1A
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FINAL REPORT

23 OCTOBER 1964

A Study of Spatial Filtering Using the Image Enhancement Viewer

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Authors:

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SYMBOLS

$F(x)$	Intensity distribution in object space
x	Object coordinate
$F(\omega)$	Amplitude distribution in frequency space
k	Linear frequency
ω	Radian frequency ($2\pi k$) coordinate
$G(\omega)$	Filter characteristic in frequency space
ω_1	Filter cutoff frequency
$H_{(z)}$	Amplitude distribution in image space
z	Image coordinate
T_2	Maximum transmission level
T_1	Minimum transmission level
c	Variance of the Gaussian pulse

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CONTENTS

FIGURES

TABLES

1. INTRODUCTION

The work done under the present phase of the contract consisted of two main parts: first, the modification of the image enhancement viewer and the testing and calibration of this instrument; second, the continuance of research, in certain areas, which had been carried out by _____ while working under previous contracts for the viewer.

A description of the modified viewer, along with the methods of testing and calibration, is contained in the operating manual. The viewer was put in working order to the specifications listed in the manual.

The following five research areas were investigated:

1. A nonsharp, Gaussian pulse was theoretically passed through an optical, coherent system. The low frequencies of the pulse were filtered with a high pass occluding filter, and the final images were plotted.

2. A filmed nonsharp edge was experimentally filtered using the viewer, and the image of the edge was traced with a scanning photometer. The results of this trace were curve fitted, normalized, and plotted.

3. Techniques (in this study, mainly exposure addition) for increasing edge contrast and sharpness using the viewer were experimentally examined.

4. The application of various filtering techniques using actual aerial photographs was studied.

5. Finally, the use of occluding spatial filtering as a tool in the area of photographic mensuration was investigated.

From the study of these five areas, a comprehensive view of the capabilities and limitations of the image enhancement viewer and occluding spatial filtering may be obtained.

1

2. THEORETICAL STUDY OF THE EFFECT OF OCCLUDING FILTERS ON AN UNSHARP (GAUSSIAN) PULSE

A full description of the image enhancement viewer (Fig. 1) and its basic properties may be
STAT found in both the operation manual and ☐ Technical Report OD-61-6. In operation, the viewer employs coherent illumination, permitting an analysis of the system to treat it as being linear in amplitude.

Since all object films used in the system are immersed in an index matching fluid (see manual) there should be no shift in phase, and the object may be considered solely in terms of amplitude.

In order to obtain a general idea of the effect of occluding filtering on amplitude objects, a generalized case (considered Gaussian for mathematical simplicity) was considered theoretically. This Gaussian pulse is tranformed into the frequency plane and there filtered by a circular, centered occluding filter of generalized dimension. The resulting distribution is then again transformed into a filtered image, which has been computed and plotted for the range at representative values.

Considering a nonsharp pulse of Gaussian form (Fig. 2)

$$f_1(x) = T_2 - (T_2 - T_1) \exp(-cx^2)$$

where $f_1(x)$ is the intensity distribution of a dark-centered pulse in the object plane. Its amplitude spectrum in the frequency plane is given by

$$F(\omega) = \int_{-\infty}^{\infty} [f_1(x)]^{\frac{1}{2}} \exp(-i\omega x) \, dx$$

Then, $[f_1(x)]^{\frac{1}{2}}$ may be rewritten in the following form

$$[f_1(x)]^{\frac{1}{2}} = [T_2 - (T_2 - T_1) \exp(-cx^2)]^{\frac{1}{2}}$$

$$= \sqrt{T_2} \left[1 - \left(1 - \frac{T_1}{T_2} \right) \exp(-cx^2) \right]^{\frac{1}{2}}$$

Expanding, we get

2

$$\left[1 - \left(1 - \frac{T_1}{T_2}\right) \exp\left(-cx^2\right)\right]^{\frac{1}{2}} = 1 - \frac{1}{2}\left(1 - \frac{T_1}{T_2}\right)\exp\left(-cx^2\right) - \frac{1}{2 \times 4}\left(1 - \frac{T_1}{T_2}\right)^2 \exp\left(-2cx^2\right)$$

$$- \frac{1 \times 3}{2 \times 4 \times 6}\left(1 - \frac{T_1}{T_2}\right)^3 \exp\left(-3x^2\right)$$

$$- \frac{1 \times 3 \times 5}{2 \times 4 \times 6 \times 8}\left(1 - \frac{T_1}{T_2}\right)\exp\left(-4cx^2\right)$$

$$- \frac{1 \times 3 \times 5 \times 7}{2 \times 4 \times 6 \times 8 \times 10}\left(1 - \frac{T_1}{T_2}\right)^5 \exp\left(-5cx^2\right) - \ldots$$

Letting the binomial coefficients be

$$A(1) = \frac{1}{2}$$

$$A(2) = \frac{1}{2 \times 4}$$

$$A(3) = \frac{1 \times 3}{2 \times 4 \times 6}$$

$$A(4) = \frac{1 \times 3 \times 5}{2 \times 4 \times 6 \times 8}$$

$$A(5) = \frac{1 \times 3 \times 5 \times 7}{2 \times 4 \times 6 \times 8 \times 10}$$

$$\vdots$$

Then $\left[1 - \left(1 - \dfrac{T_1}{T_2}\right)\exp\left(-cx^2\right)\right]^{\frac{1}{2}} = 1 - \displaystyle\sum_{n=1} A(n)\left(1 - \dfrac{T_1}{T_2}\right)^n \exp\left(-ncx^2\right)$

Putting this in the integral

$$F(\omega) = \int_{-\infty}^{\infty} \sqrt{T_2}\left[1 - \sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)^n \exp\left(-ncx^2\right)\right]\exp\left(-i\omega x\right)\,dx$$

Using the cosine transform, because of symmetry, and the aperture limits

$$F(\omega) = 2\sqrt{T_2}\int_0^{x_f} \cos \omega x\,dx - 2\sqrt{T_2}\sum_{n=1} A(n)\left(1 - \frac{T_2}{T_1}\right)^n \int_0^{\infty} \exp\left(-ncx^2\right)\cos \omega x\,dx$$

Integrating

$$F(\omega) = 2\sqrt{T_2}\,x_f\,\text{sinc}\,(\omega x_f) - \sqrt{T_2}\sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)^n \frac{\sqrt{\pi}}{\sqrt{nc}}\exp\left(-\omega^2/4nc\right)$$

3

This pulse may also have a light center in the form

$$f_2(x) = T_1 + (T_2 - T_1) \exp(-cx^2)$$

The expansion and analysis using this pulse is very similar to that of $f_1(x)$.

We now obtain the image of $f_1(x)$, after passing it through a symmetric, sharp cutoff occluding filter (see Fig. 3) centered in the frequency plane whose characteristic is

$$G(\omega) = 1 \qquad\qquad (\omega_1 \le \omega < \infty)$$
$$G(\omega) = 0 \qquad\qquad (0 < \omega < \omega_1)$$

The distribution in the image plane is given by the following transform

$$h_1(z) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) \, G(\omega) \exp(i\omega x) \, d\omega$$

Again, for reasons of symmetry, we may use the cosine transform

$$h_1(z) = \frac{1}{\pi} \int_{\omega_1}^{\infty} F(\omega) \cos(\omega z) \, d\omega$$

$$= \frac{2\sqrt{T_2}}{\pi} x_f \int_{\omega_1}^{\infty} \text{sinc}(\omega x_f) \cos(\omega z) \, d\omega$$

$$- \frac{\sqrt{T_2}\sqrt{\pi}}{\pi} \int_{\omega_1}^{\infty} \sum_{n=1}^{\infty} A(n) \left(1 - \frac{T_2}{T_1}\right)^n \frac{1}{\sqrt{nc}} \left[\exp(-\omega^2/4nc)\right] \cos(\omega z) \, d\omega$$

$$= \frac{2\sqrt{T_2}}{\pi} x_f \int_0^{\infty} \text{sinc}(\omega x_f) \cos(\omega z) \, d\omega - \frac{2\sqrt{T_2}}{T_2} x_f \int_0^{\omega_1} \text{sinc}(\omega x_f) \cos(\omega z) \, d\omega$$

$$- \frac{\sqrt{T_2}}{\sqrt{\pi}} \sum_{n=1}^{\infty} A(n) \left(1 - \frac{T_1}{T_2}\right)^n$$

$$\times \frac{1}{\sqrt{nc}} \left[\int_0^{\infty} \exp(-\omega^2/4nc) \cos(\omega z) \, d\omega - \int_0^{\omega_1} \exp(-\omega^2/4nc) \cos(\omega z) \, d\omega\right]$$

Applying the trigonometric identity

$$\sin(\omega x_f) \cos(\omega z) = 1/2 \sin(x_f + z)\omega + \sin(x_f - z)\omega$$

and integrating, we get

4

$$h_1(z) = \frac{\sqrt{T_2}}{\pi}\left[\frac{\pi}{2} + \frac{\pi}{2}\right] - \frac{\sqrt{T_2}}{\pi}\,Si\,(x_f + z)\omega_1 - \frac{T_2}{\pi}\,Si\,(x_f - z)\omega_1$$

$$- \frac{\sqrt{T_2}}{\sqrt{\pi}}\sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)\frac{1}{\sqrt{nc}}\,\sqrt{n\pi c}\,\exp\,(-cnz^2)$$

$$+ \frac{\sqrt{T_2}}{\sqrt{\pi}}\sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)^m\frac{1}{\sqrt{nc}}\int_0^{\omega_1}\exp\,(-\omega^2/4nc)\,\cos\,(\omega z)\,d\omega$$

Finally, the pulse image is given by

$$h_1(z) = \sqrt{T_2} - \frac{\sqrt{T_2}}{\pi}[Si\,(x_f + z)\omega_1 + Si\,(x_f - z)\omega_1]$$

$$- \sqrt{T_2}\sum_{n=1} A_n\left(1 - \frac{T_1}{T_2}\right)^n\exp\,(-cnz^2)$$

$$+ \frac{\sqrt{T_2}}{\sqrt{\pi}}\sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)^n\frac{1}{\sqrt{nc}}\int_0^{\omega_1}\exp\,(-\omega^2/4nc)\,\cos\,(\omega z)\,d\omega$$

Rewriting the image term in the following form

where $a = \dfrac{\omega_1}{\sqrt{2c}}$

$m = z\sqrt{2c}$

$\dfrac{\omega}{\omega_1} = t$

$d\omega = \omega_1\,dt$

$$h_1(a, m) = \sqrt{T_2} - \frac{\sqrt{T_2}}{\pi}[Si\,(x_f\sqrt{2c} + m)a + Si\,(x_f\sqrt{2c} - m)a]$$

$$- \sqrt{T_2}\sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)^n\exp\,(-nm^2/2)$$

$$+ \frac{\sqrt{T_2}}{\sqrt{\pi}}\sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)^n\frac{a}{\sqrt{2n}}\int_{-1}^{1}\exp\,(-a^2t^2/2n)\,\cos\,(amt)\,dt$$

Since c, the pulse variance is large, then $x_f\sqrt{2c}$ is large and the value of $Si\,(x_f\sqrt{2c} \pm m)\,a$ approaches $\pi/2$. Under this condition, the image reduces to

5

$$h_1(a,m) = -\sqrt{T_2} \sum_{n=1} A(n)\left(1 - \frac{T_1}{T_2}\right)\exp\left(-nm^2/2\right)$$

$$+ \frac{\sqrt{T_2}}{\sqrt{\pi}} \sum_{n=1} A_n\left(1 - \frac{T_1}{T_2}\right)^n \frac{a}{\sqrt{2n}} \int_{-1}^{1} \exp\left(-a^2t^2/2n\right)\cos\left(amt\right)dt$$

At this point, it is necessary to compute the values of the integral

$$\frac{a}{\sqrt{2\pi n}} \int_{-1}^{1} \exp\left(-a^2t^2/2n\right)\cos\left(amt\right)dt$$

Upon receiving these values, it is then possible to normalize the total energy of the filtered cases to the unfiltered case.

The cases computed were those where a had the values of 1/4, 1/2, 1, and 2, and n varied from 1 to 5; m was taken in steps of 0.05 from 0 to 3.0; T_1 was taken in steps of 0.01 from 0 to 0.99; and T_2 was set at 1.0.

The normalization procedure is the following

$$\int_{-\infty}^{\infty} \frac{h^2(a,m)}{T_2} = I(a,m)$$

which is normalized to the total energy of the unfiltered pulse $A_p = I(0,m)$ where a = 0. Therefore, the normalization factor is

$$N = \frac{A_p}{I(a,m)}$$

The area of the filtered image, $I(a,m)$, is approximated by Simpson's rule for normalization purposes.

Representative results of the computations were plotted (see Fig. 4, a through h).

The parameters relating k, the linear frequency, and c, the pulse variance for a's varying from 0 to 2, are plotted in Fig. 5. This relationship is defined by

$$c = \frac{2\pi^2 k^2}{a^2}$$

For the entire range of edge contrast (variation of T_1), the smaller filter sizes give the expected results, i.e., increased normalized contrast for increased filter size. The larger filter sizes give rather unexpected and varying results for changing contrast. A full explanation for this phenomenon cannot be made without further study.
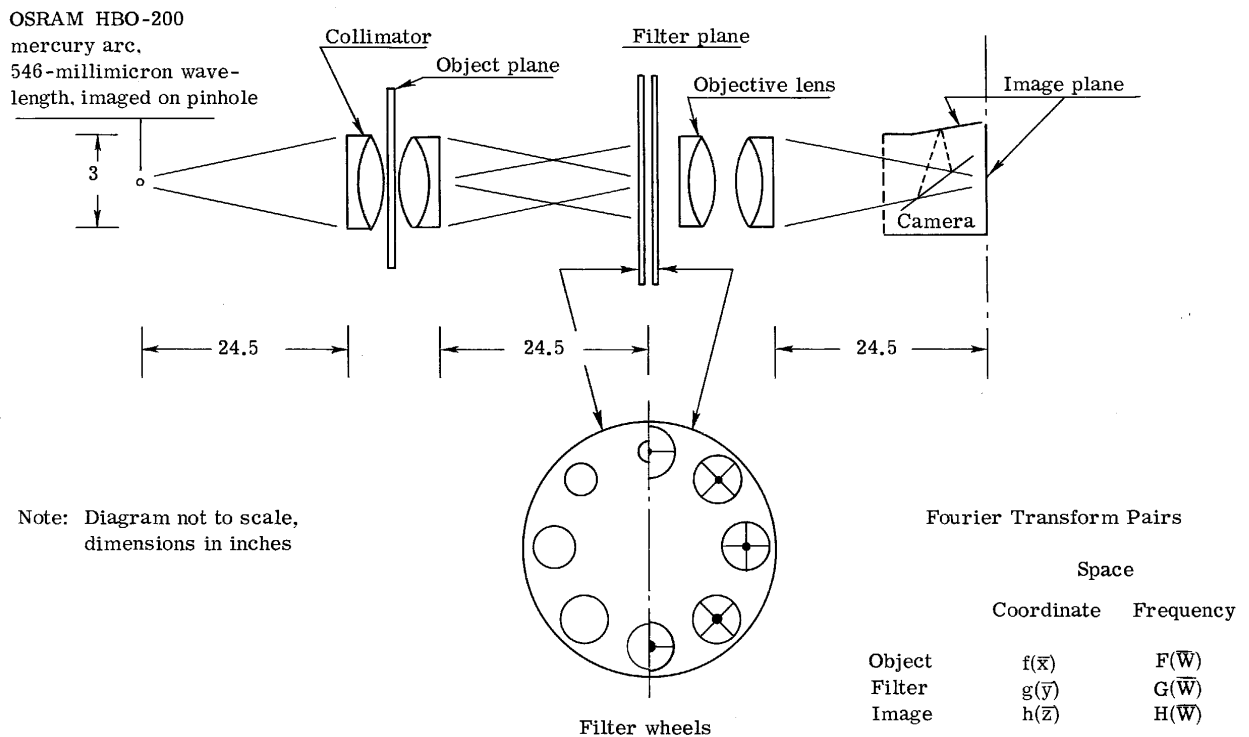
6

OSRAM HBO-200
mercury arc,
546-millimicron wave-
length, imaged on pinhole

Collimator

Object plane

Filter plane

Objective lens

Image plane

3

24.5

24.5

24.5

Camera

Note: Diagram not to scale,
dimensions in inches

Filter wheels

Fourier Transform Pairs

Space

	Coordinate	Frequency
Object	$f(\overline{x})$	$F(\overline{W})$
Filter	$g(\overline{y})$	$G(\overline{W})$
Image	$h(\overline{z})$	$H(\overline{W})$

Fig. 1 — Linear, coherent optical system showing focal planes of interest
and defining the notation and location of the Fourier transform planes
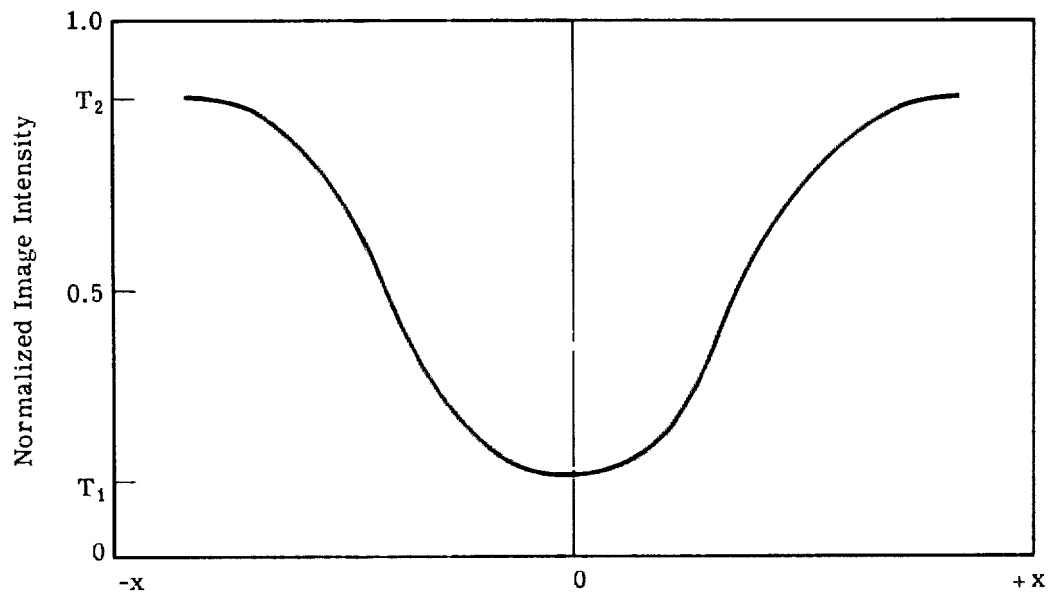
(a) Dark-centered pulse
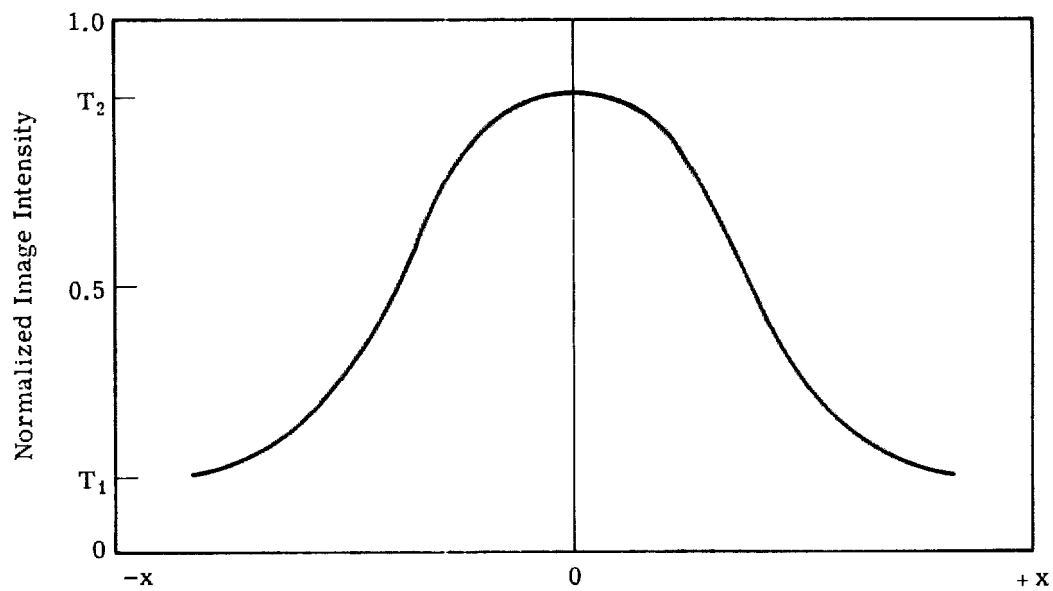
(b) Light-centered pulse

Fig. 2 — Intensity distribution of a dark- and a light-centered Gaussian spatial pulse
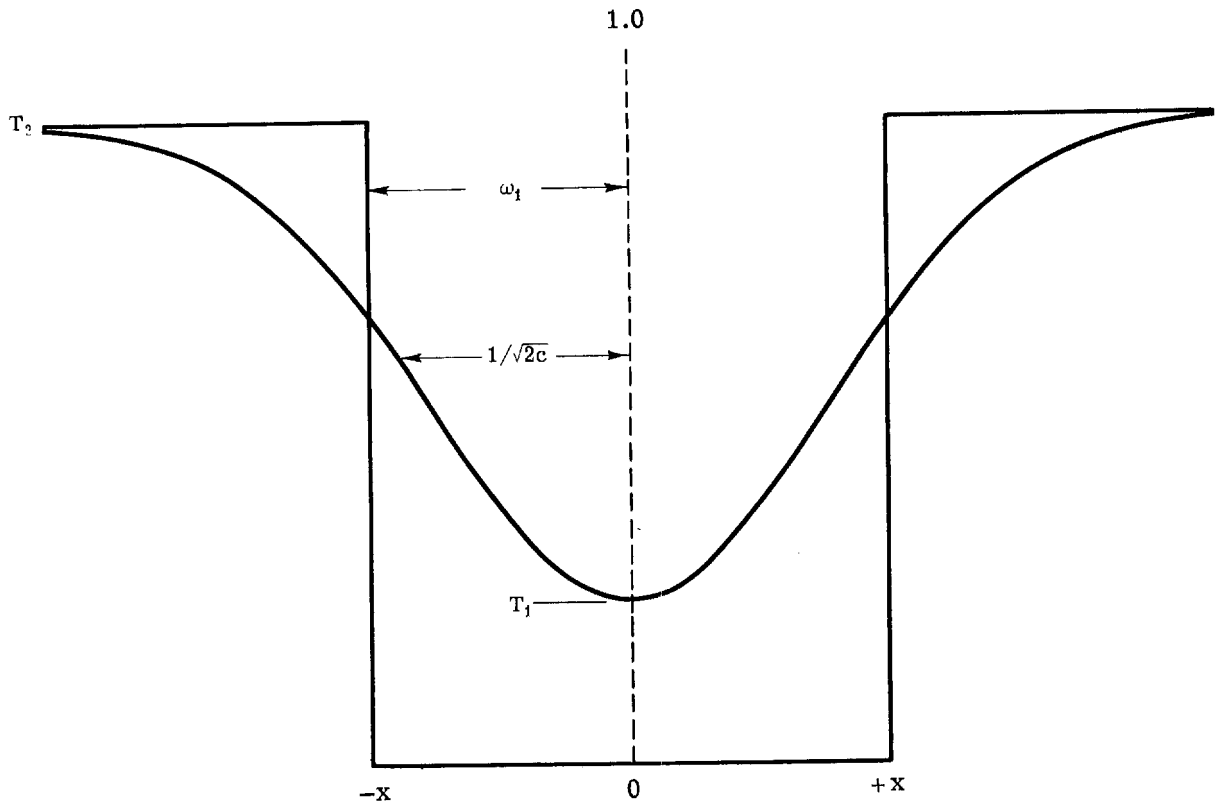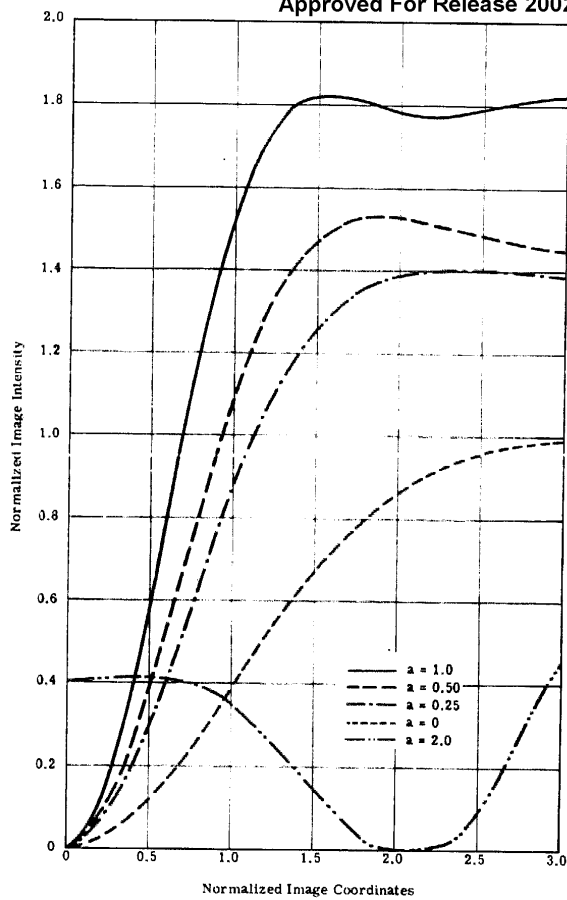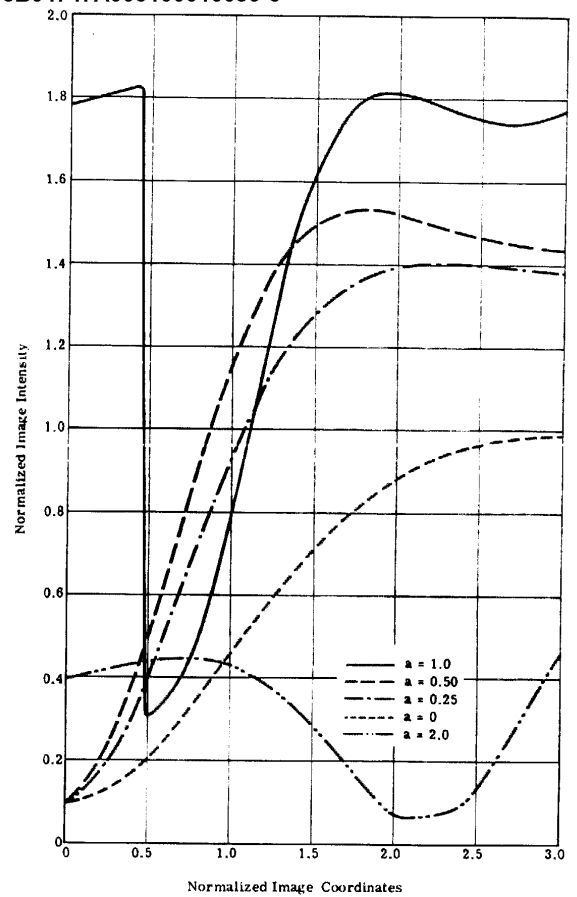
8

Fig. 3 — Intensity distribution of a dark-centered Gaussian spatial pulse with an occluding spatial filter of radius ω_1, showing some of the important pulse and filter constants
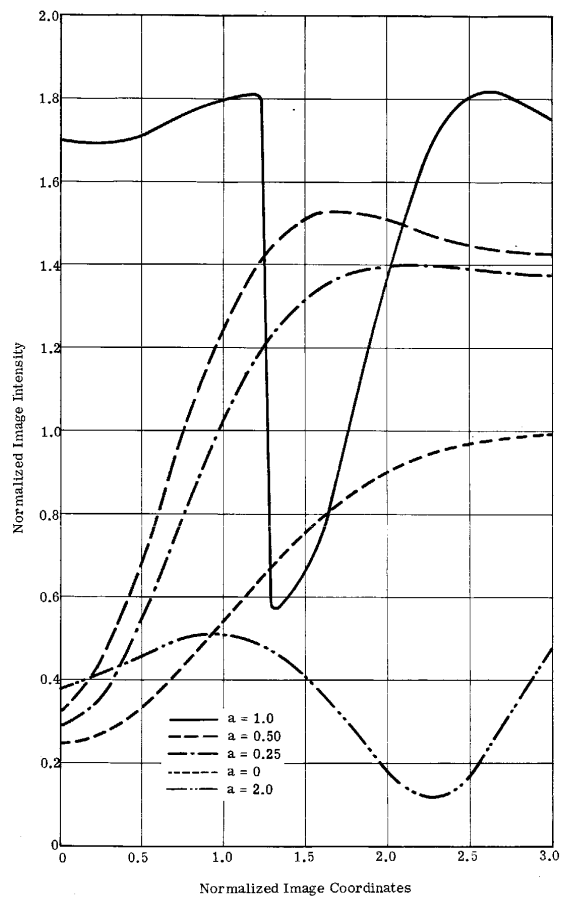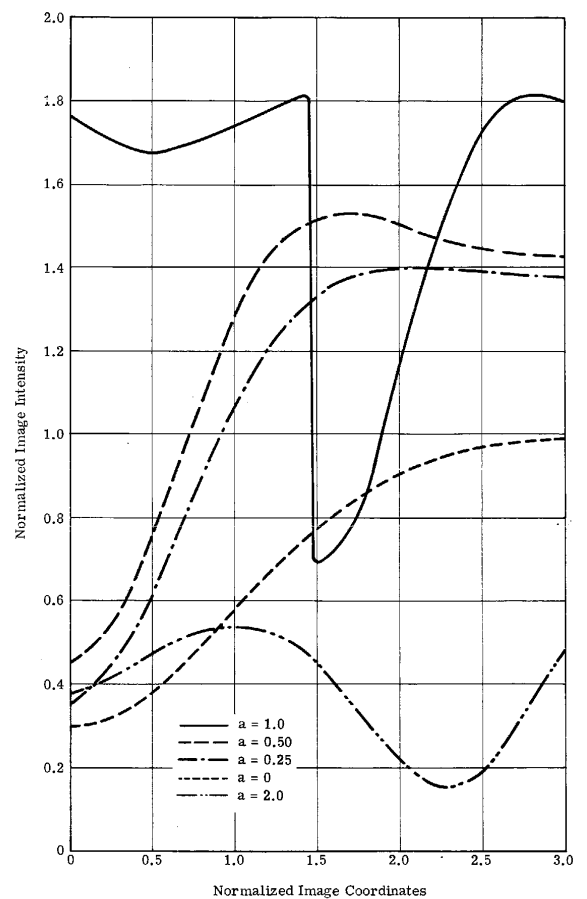
9

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(a) $T_1 = 0$

(b) $T_1 = 0.1$

Fig. 4 — Images of nonsharp Gaussian pulses of varying minimum transmissive level, filtered with occluding spatial filters in a linear, coherent optical system
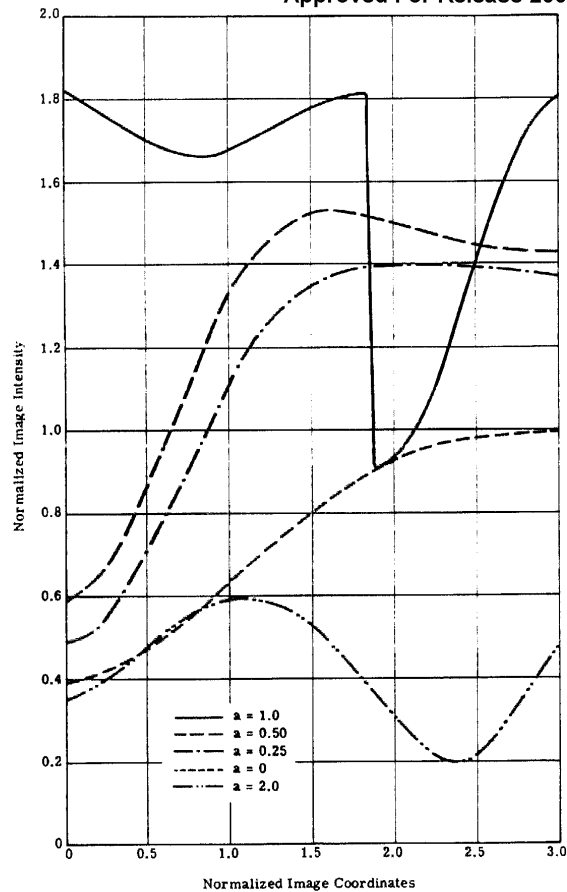
Normalized Image Intensity

Normalized Image Coordinates

a = 1.0
a = 0.50
a = 0.25
a = 0
a = 2.0

(c) $T_1 = 0.25$

Normalized Image Intensity

Normalized Image Coordinates
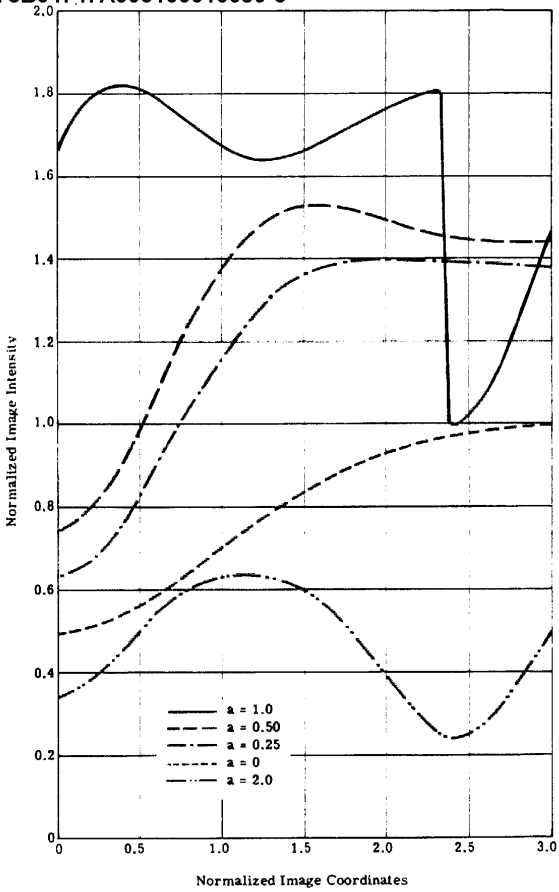
a = 1.0
a = 0.50
a = 0.25
a = 0
a = 2.0

(d) $T_1 = 0.30$
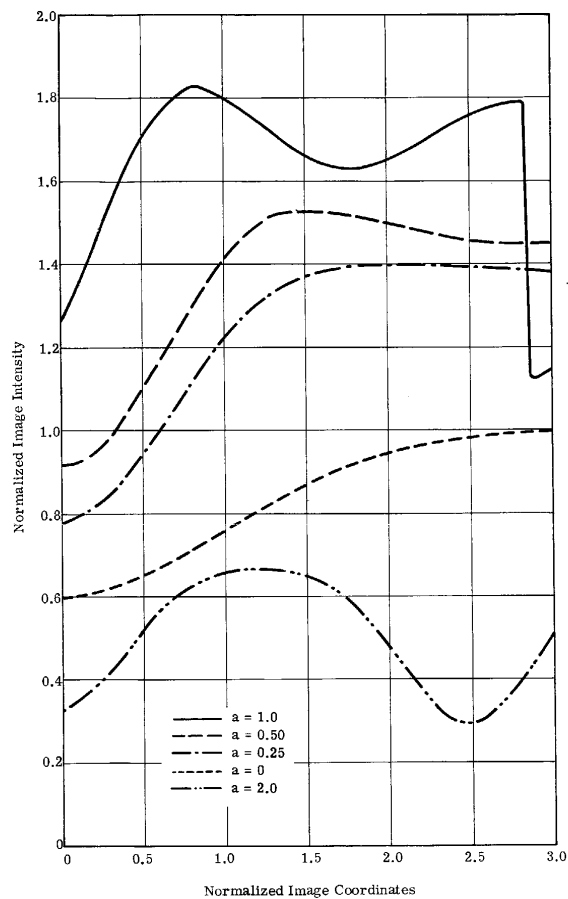
Fig. 4 — (Cont.)
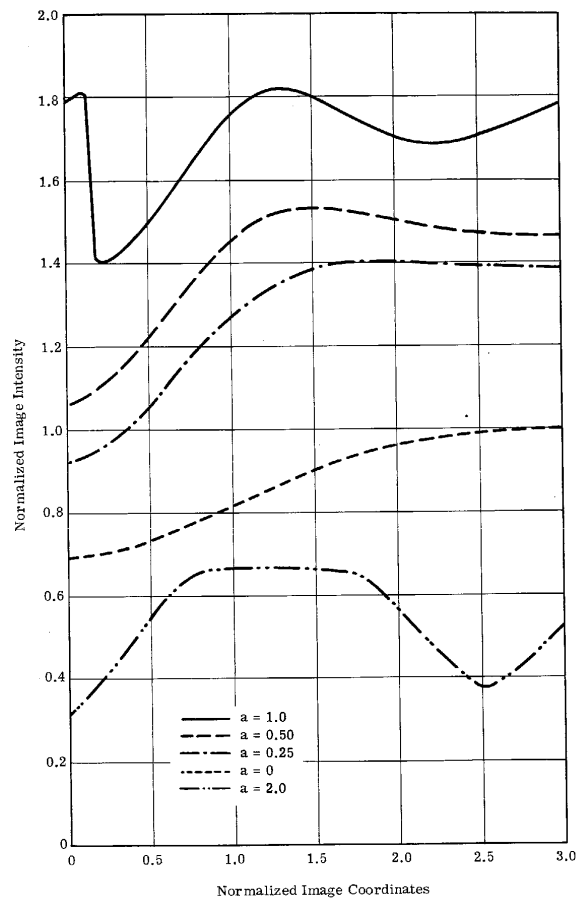
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(e) $T_1 = 0.4$

(f) $T_1 = 0.5$

Fig. 4 — (Cont.)

(g) $T_1 = 0.6$

(h) $T_1 = 0.7$
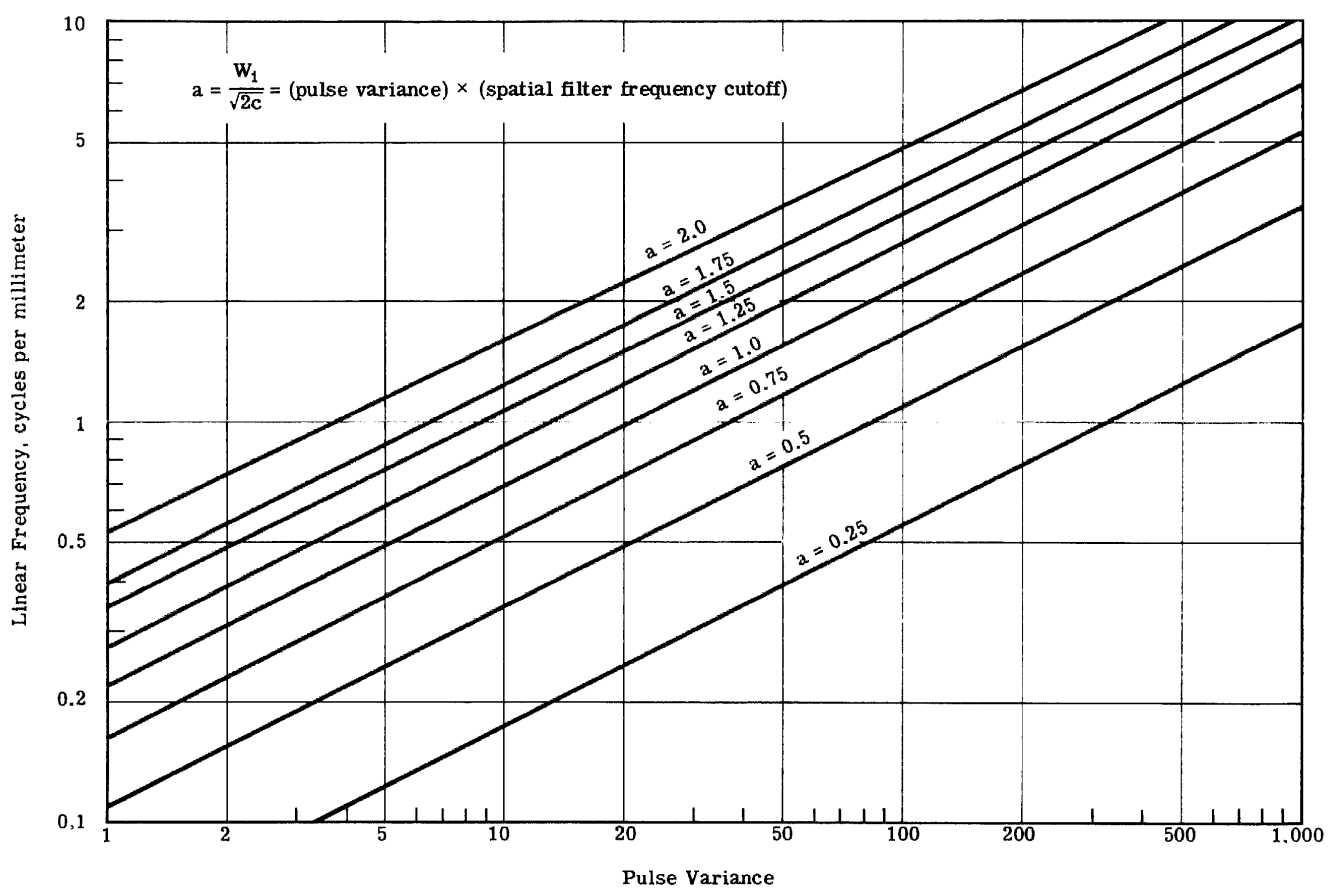
Fig. 4 — (Cont.)

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Fig. 5 — Parameters relating the linear frequency, k, the pulse variance, c,
for values of a = 0, 0.25, 0.50, 1.0, 1.5, and 2.0

3. EXPERIMENTAL FILTERING OF A NONSHARP EDGE

In order to substantiate the theoretical work, an experiment was designed with conditions approximating the analysis.

Instead of a pulse, a filmed nonsharp edge was used as an object. This was placed in the object plane of the image enhancement viewer. Though the shape of this pulse had first been assumed to be Gaussian, subsequent traces revealed a number of un-Gaussian characteristics which could well affect the resulting filtered traces.

Because an edge and not a pulse was used, the filters placed in the object plane did not have to be circular (the frequency distribution being one dimensional). The occluding filters used were pieces of drill rod whose width was accurately known. These filters were then carefully centered in the frequency (or filter) plane.

Using a scanning photometer whose slit width was minimized to the point where, at maximum photometer sensitivity, using the largest filter, 100 percent deflection on the recorder (5-millivolt range) could be reached. The edge was then traced with the photometer placed in the image plane with its slit parallel with the edge. First, the image of the edge with no occluding filter and the images of the edge with filters corresponding to a = 1.5 and a = 2.5 were traced.

The actual traces for the three cases are shown in Fig. 6. (The two filtered cases are expanded by a factor of 10 in the intensity scale.)

The resulting filtered cases were normalized to the area under the unfiltered curve in the same manner as used in the theoretical traces. The resulting curves are plotted in Fig. 7. Because the normalized cases are meant to be compared with the theoretical Gaussian, only the part of the edge corresponding to a pulse (center $1/\sqrt{2c}$ distance from the inflection point) is taken.

Because of differences between the experimental edge and the Gaussian pulse taken in part 1, and the limitations in filter size (it was not possible to obtain smaller filters), no conclusion can be drawn from the results, though a general agreement may be found.
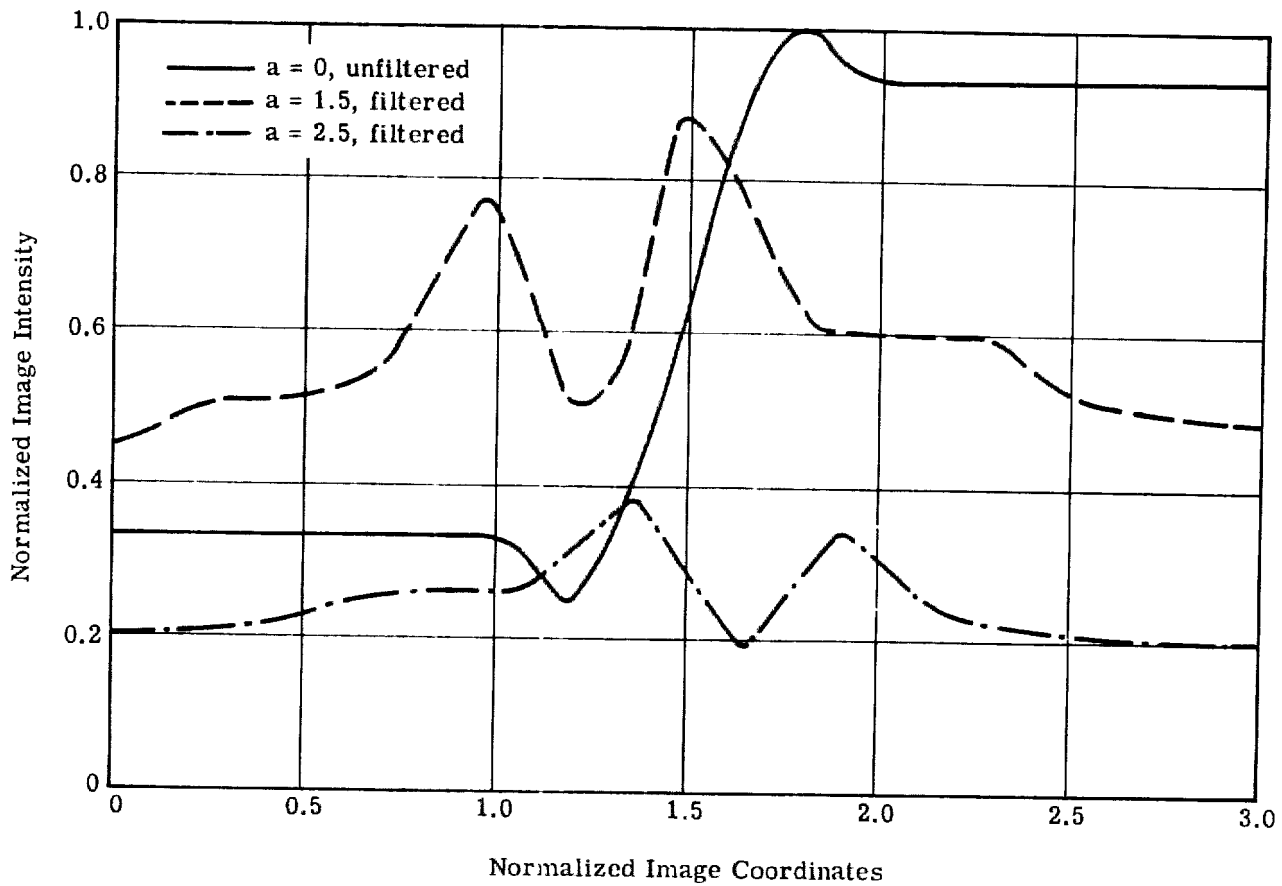
Fig. 6 — Plots of the intensity distribution in the aerial image of an unfiltered and two filtered edges (a = 1.5 and 2.5)
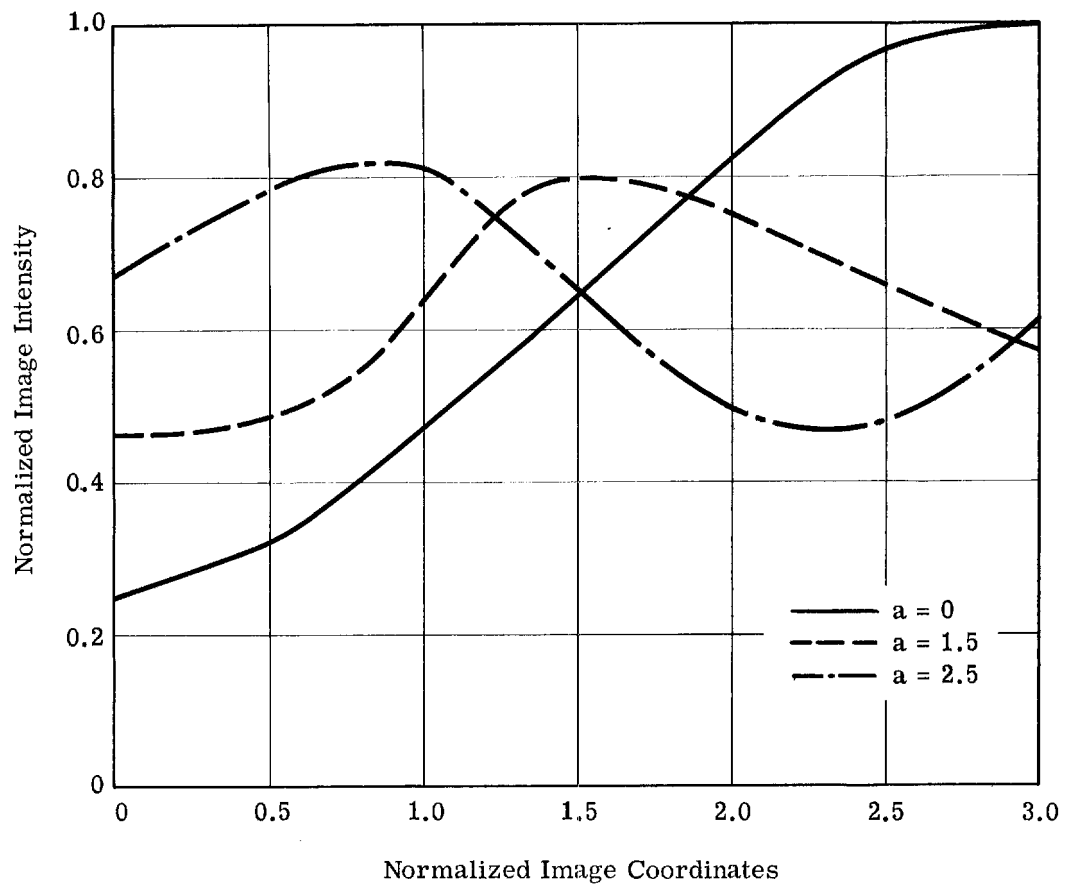
Fig. 7 — Normalized (to total area under unfiltered curve) intensity distribution of the image of two experimentally filtered edges

4. EDGE ENHANCEMENT THROUGH EXPOSURE ADDITION

The next area to be investigated was that of actually applying filtering techniques in order to enhance an edge on a photographic emulsion. This edge may be enhanced in two different ways: (1) increase in contrast, and/or (2) increase in slope.

Two methods for producing such enhancement using the image enhancement viewer have been considered. The first is called exposure addition. In this method, an unfiltered edge is exposed on an emulsion, after which an occluding filter is placed in the system and, without changing the position of either the edge or the film, a second exposure is made on the same frame. The second method is transmission multiplication. Here, two exposures are made on two separate frames; one exposure is unfiltered, the other is filtered to some degree. These two frames are then combined, using some sort of enlarging technique, in various proportions. Obviously, the difficulty in this method is the alignment of the two negatives, which is quite critical. This must be done with an accuracy that entails a great deal of technical ability.

It was possible to do some work in the area of exposure addition, using the test edges from the previous area, but because of time limitation, it was impossible to do any transmission multiplication.

An edge was exposed, using several occluding filters with varying exposure times, mixing the filtered and unfiltered parts. These edges were then microdensitometered on our Intectron instrument. For these traces, an effective 3-micron slit was used. The results of these traces have been recorded in Table 1.

Tables 1 and 2 are based upon exposures 1 to 19. The slopes (Table 1) and edge contrasts (Table 2) are those read, averaged, and weighted from several microdensitometer traces, varied for relative slit position with the edge. Included is the sensitometric curve relevant for the longer exposure times. Given also are the exposure times and the maximum densities (upper point through which the slope passes). As can be seen, some of these values are well up on the shoulder of the sensitometric curve (Fig. 8). All of the exposures were on 70-mm Panatomic-X film. A plot of the measured edge slopes against the ratio of filtered to unfiltered exposure time is plotted in Fig. 9.

From this data it may be concluded that, with correct mixtures of filtered and unfiltered exposures, it is possible to equal or even slightly surpass the slope of the original edge.

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Table 1 — Slope of Traced, Enhanced Edges

Exposure No.	Filter Diameter, in.	Average Slope	Unfiltered Time, sec	Filtered Time, sec
1	—	4.5	1/2	—
2	—	3.5	1	—
3	0.015	3.2	1/2	1
4	0.015	2.5	1/2	2
5	0.015	3.6	1/2	4
6	0.015	4.3	1	1
7	0.015	2.8	1	2
8	0.015	2.4	1	4
9	0.025	2.8	1/2	2
10	0.025	4.0	1/2	4
11	0.025	4.1	1/2	8
12	0.025	2.8	1	4
13	0.025	2.9	1	8
14	0.041	2.8	1/2	4
15	0.041	3.1	1/2	8
16	0.041	5.0	1/2	16
17	0.041	3.2	1	4
18	0.041	2.0	1	8
19	0.041	1.9	1	16

Table 2 — Contrast of Traced, Enhanced Edges

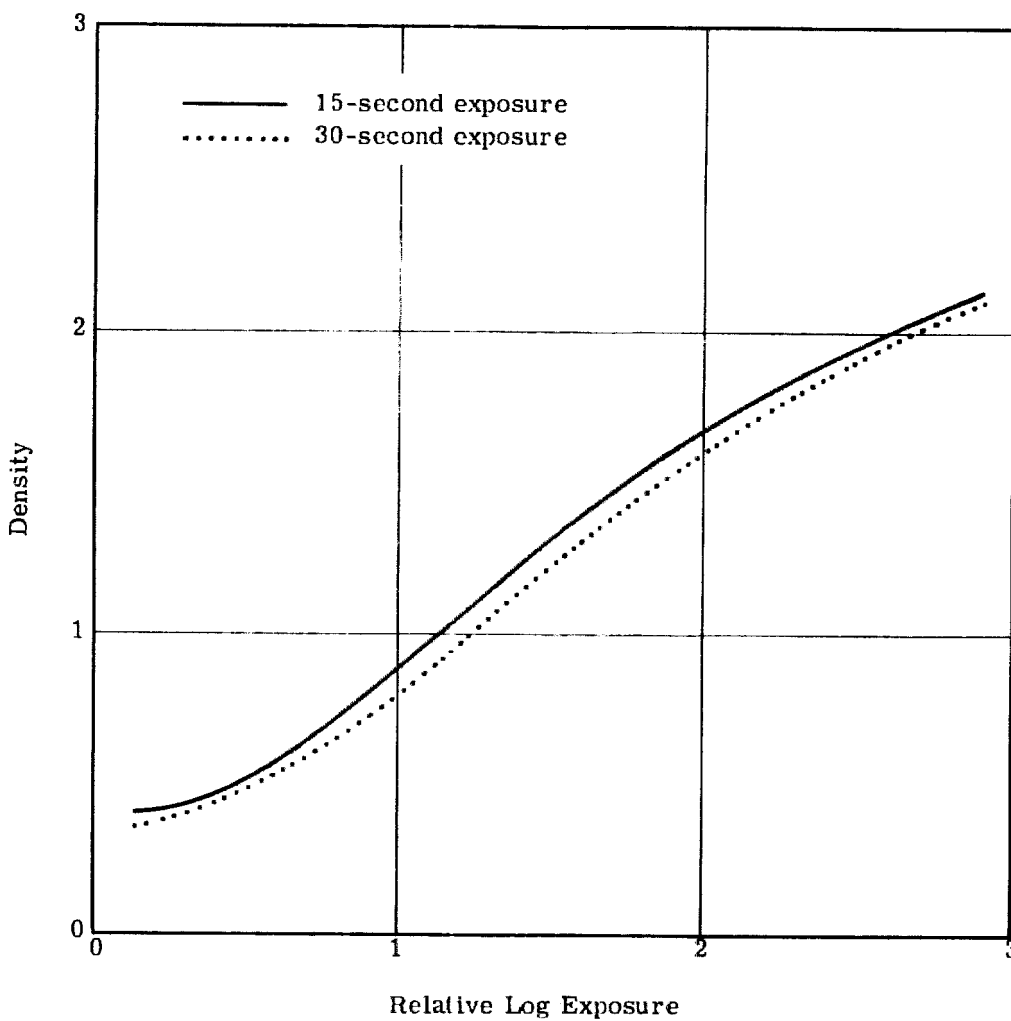| Exposure No.	Minimum Density	Maximum Density	Contrast
1	0.60	1.50	0.90
2	0.95	1.20	0.85
3	0.85	1.45	0.60
4	1.35	1.80	0.45
5	1.55	1.90	0.35
6	1.15	1.85	0.70
7	1.50	2.00	0.50
8	1.40	1.90	0.50
9	0.80	1.55	0.75
10	1.20	1.70	0.50
11	1.00	1.60	0.60
12	1.10	1.80	0.70
13	1.35	1.85	0.50
14	0.85	1.55	0.70
15	0.75	1.50	0.75
16	0.90	1.55	0.65
17	0.95	1.70	0.75
18	1.30	1.80	0.50
19	1.65	2.25	0.60

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Fig. 8 — Sensitometric curves for enhanced edges on Panatomic-X film developed in D-19 for 6 minutes
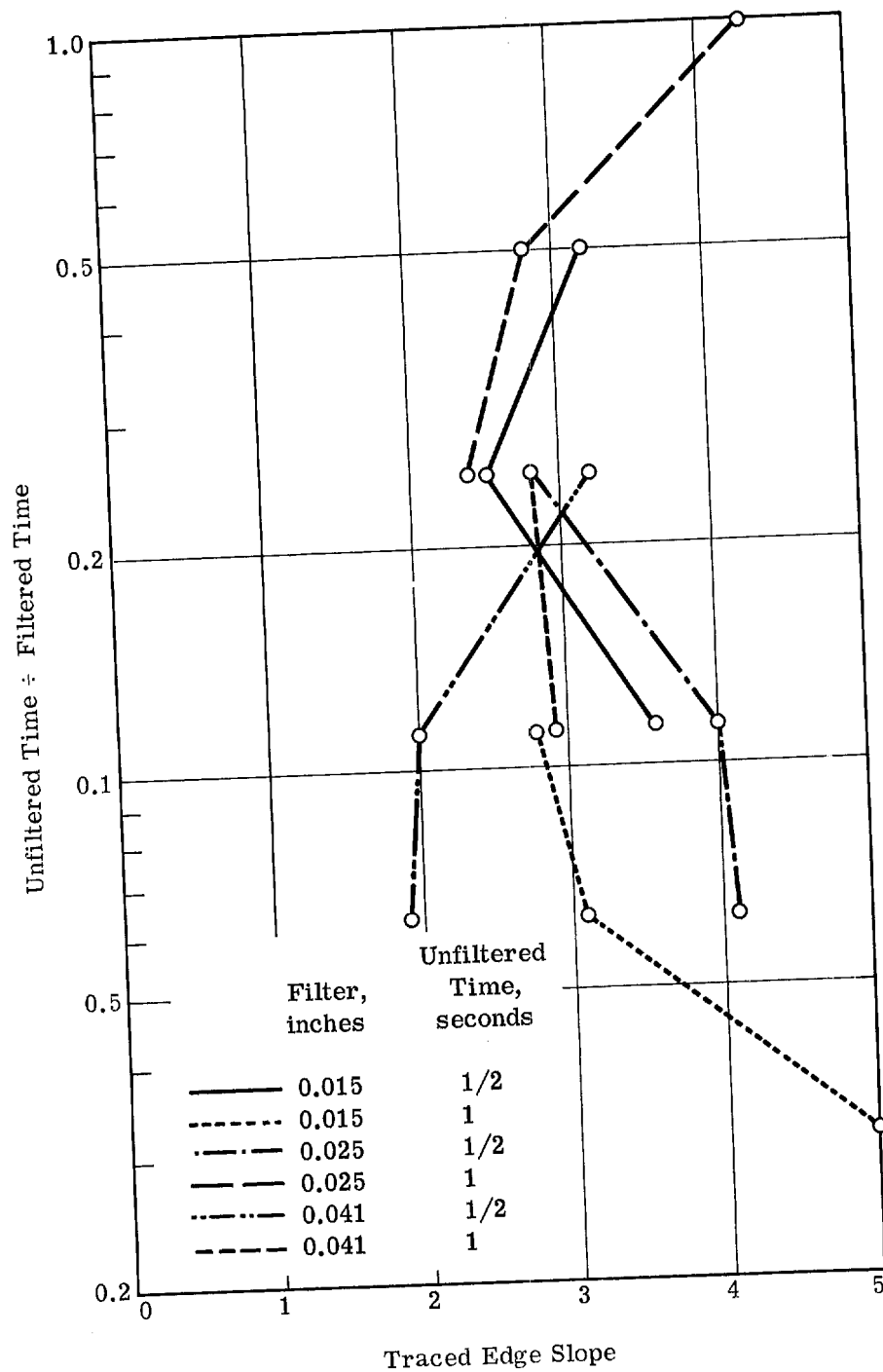
Fig. 9 — Change of slope of an edge with a varying ratio of unfiltered time to filtered time using the technique of exposure addition

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5. APPLICATION OF SPATIAL FILTERING TO THE EXAMINATION OF AERIAL PHOTOGRAPHS

As part of the studies with the image enhancement viewer, it was considered desirable to examine some aerial negatives with various degrees of spatial filtering. The reason for this was that it is sometimes thought that details below the limit of detection can be brought above this threshold by suitable filtering. Also, it is conceivable that recognition of poorly defined objects might be improved by a controlled filtering which causes ringing at the edges.

When the detail to be detected has a well defined spectrum, or a known pattern, spatial filtering has definite advantages. For example, a sinusoidal frequency of low modulation, recorded photographically, may be invisible against a grainy background, but by use of a spatial filter permitting only that frequency to pass, the grain noise is eliminated from the reconstituted image and the sinusoidal pattern may be seen. To be more precise, only those components of the grain frequency spectrum which lie in the passband of the filter remain to obscure the wanted image, and if the grain spectrum is flat, this gives a great improvement in signal-to-noise ratio. However, this is an ideal case for the use of filtering, since the signal spectrum is concentrated at one point in the diffraction plane, while the noise spectrum is widely distributed across the plane. When the object is more complex—for example, a square wave instead of a sine wave—its spectrum theoretically extends to infinity, and noise cannot be reduced without distorting the signal to some degree. If the significant feature of the object, however, is its repetitive nature and not the shape of the waves, the filtering can be as effective as for the sinusoidal pattern. For aerial scenes in general, little or no improvement can be expected from spatial filtering, because the details, consisting of sharp edged lines or similar, simple, nonrepetitive shapes, have very complex spectra. Filtering to reduce noise can only be effective if the objects of interest have simple, known spectra, for which individual filters can be made in advance.

To test these ideas under a realistic approximation to operational conditions, the following experiment was carried out with a setup which was being used in another program. Simulated aerial photographs were made by photographing a transparency made under controlled tone reproduction conditions from a large scale aerial negative. The original negative scale was 1:2,000 and the reduction factor, using a 6-inch lens, was 20 to 1. Thus the copy negatives were at 1:40,000 scale. Uniform fogging light from a beam splitter was introduced during the copying, to reduce the luminance scale of the transparency to approximately 5 to 1, simulating an aerial scene viewed from a high altitude. Negatives were made on SO-243 emulsion, varying the lens-film transfer function by changing the lens aperture. These lens-film transfer functions are shown in Fig. 10; for these values of spatial frequency cutoff, granularity is not obtrusive when looking for detail in the negatives. Thus a series of negatives were available in which the quality of definition showed a progressive deterioration of known amount. The intention was to apply various kinds of filtering, and if any improvement could be seen, to equate this to the quality of the next best negative. Thus any effect of the filtering could be approximately evaluated in terms of the definition of conventionally viewed photographs.

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The original 1:40,000 scale negatives, being only 1 centimeter in diameter, were enlarged 6×, the resulting positive transparencies being more convenient for viewing in the spatial filtering apparatus. (It was known, from work in the other programs referred to above, that the enlarging process introduced no significant loss of quality even for the best negative.)

After repeated trials of filtering, both high pass and low pass, it was concluded that no choice of frequency band enabled anything to be seen which could not be seen as well or better in normal viewing by incoherent light. Indeed, due to the disturbing effect of the ringing around small particles of dirt which had not been completely removed from the negatives or filtered from the fluid, the incoherent viewing was always preferred. In a few instances it was felt that the edges of isolated objects such as trucks might have been more clearly defined when using a high pass filter, but this effect was so small (if it existed) that a followup with more precise experimentation was not justified.

This negative conclusion is in accordance with the theoretical expectations, as discussed earlier in this section.

It should perhaps be stressed that these findings do not imply that coherent light techniques have no value for the detection of previously known patterns.
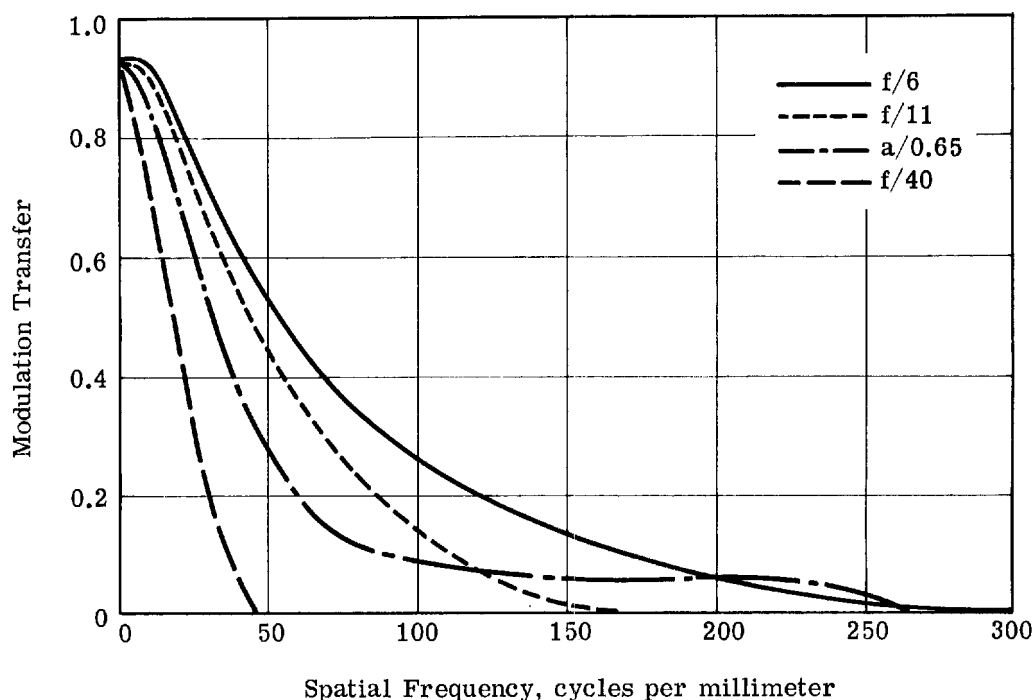

Fig. 10 — Four lens-film transfer functions using SO-243 film

6. APPLICATION OF SPATIAL FILTERING TO MENSURATION

The most obvious practical application of the phenomena produced when the techniques of the image enhancement viewer are used on filmed objects is in connection with mensuration. By using the ringing effect found in the vicinity of the edge, it is possible that the location of the edge may be determined with a greater degree of accuracy than may be otherwise obtained.

Using the viewer, an experiment was devised to test the relative mensurability of filtered and unfiltered edges by employing a particular measuring instrument, the [   ] Type 422C Comparator. STAT

A sharp edged, opaque, square object was photographed on SO-243 emulsion at f/6 and at f/1,000. The negatives were then enlarged to 2 by 2 inches, so as to be usable in the viewer. In order to be able to refer to the original object size, a grating of known dimensions was super-imposed on one print of the object. This was measured on the comparator, after having been en-larged and photographed on the viewer, giving the total magnification of the processes.

The objects were then placed into the viewer and photographed on 70-mm Panatomic-X film, first with no occluding filters used and then with several different sizes of occluding filters. The exposure level for all the cases was maintained at approximately the same point.

The dimensions of the photographed square used as an object in the viewer were determined in two separate manners:

1. The known size of the original cutout was multiplied by the magnification factors of the camera and the enlarger.

2. The object was measured directly on the comparator.

The results given by the two different methods matched to within 0.01 millimeter in both directions on the square.

The measurement of the objects, which had been passed through the viewer, consisted of two parts:

1. It was first necessary to measure the f/6 and f/1,000 unfiltered cases to find the accuracy to which the actual object size can be determined (after having been multiplied by a magnification factor for the viewer determined separately). It was found that there was very little difference in the ability to estimate the locations of the edges, and therefore, to measure the size of the objects, from the f/6 case to the f/1,000 case.

2. After the negatives were filtered with several different sized occluding filters, the meas-urements to determine the original object size (multiplied by the known magnification factor of the viewer, again) were repeated on the comparator.

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In the f/6 case, a strong ring was placed on the edge in all the filtering conditions, yet because of the limitations of the comparator and of the ability to place the crosshair at any point with any great accuracy, no improvement of measurement precision was found.

In the f/1,000 case, even the largest filter produced very little ringing around the edge position, and once again the filtering did not provide any marked improvement in the ability to locate the edge and measure the object size.

Measurement of the image of the filtered objects directly on the viewer was not attempted, though it was quite possible that with a more accurate measuring instrument than was used here, and without the further weakening of the ringing through the recording on film, an improved accuracy in the location of many edges may be found.

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